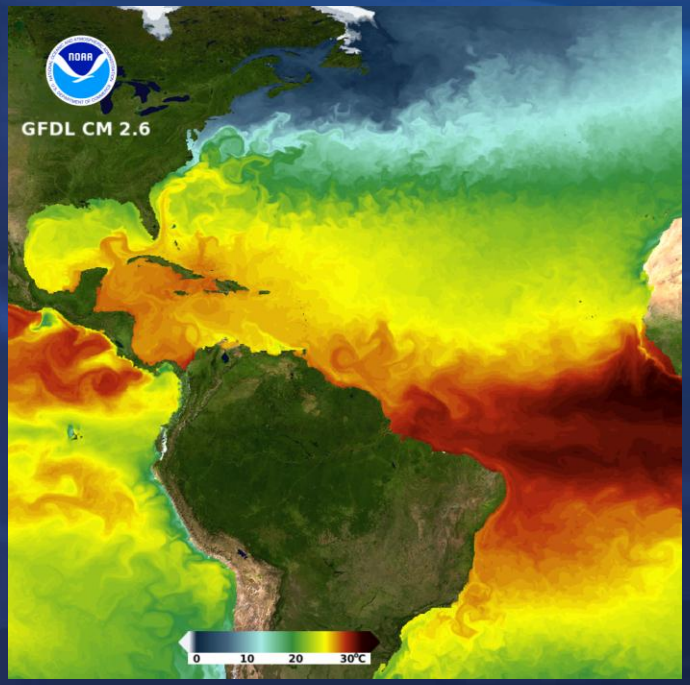
Climate modeling at GFDL –
Past, present, and future

Thomas L. Delworth
March 21, 2012

1. Synthesis of GFDL climate modeling from 2006-2012

2. Current capabilities

3. Future plans

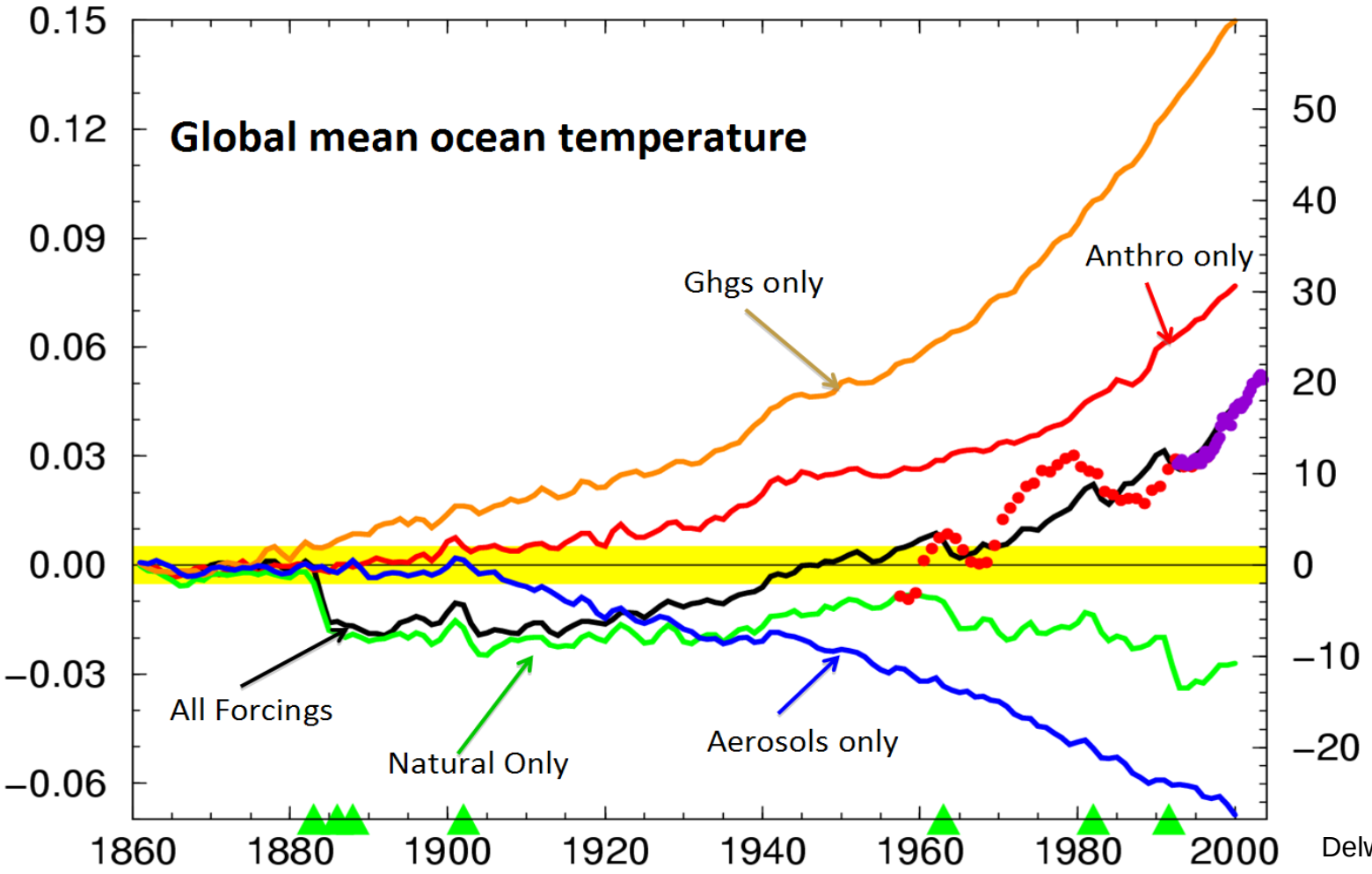


Circa 2005

CM2.0,CM2.1 – state of the art physical climate models (1º ocn; 2º atm)

IPCC AR4 Models

Attribution experiments quantify impact of various forcings in ocean warming



Delworth et al, 2005

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CM2.0,CM2.1 – state of the art physical climate models (1º ocn; 2º atm)

IPCC AR4 Models

Circa 2010

ESM2M,ESM2G
- Carbon cycle
- Vegetation feedback
- Ocean formulation

HIRAM
- High spatial resolution (atm only)
- Time-slice experiments
- Climate extremes

IPCC AR5 / CMIP5 Models

CM3 (Primary Physical Model)
- Aerosols, indirect effect
- Stratosphere
- Convection, Land Model
- Atmospheric Chemistry

CM2.5
- High spatial resolution (coupled)
- Energetic ocean
- Variability and change in coupled system at high resolution

Complexity/Completeness

Spatial Resolution

1. CM3

New atmosphere model (AM3).
Interactive tropospheric and stratospheric chemistry, aerosols & aerosol-cloud interactions.
New land model and hydrology (LM3).

2. ESM2

Carbon biogeochemistry (land and ocean), 2 ocean configurations: MOM4.1 (ESM2M) and GOLD (ESM2G, isopycnal model).

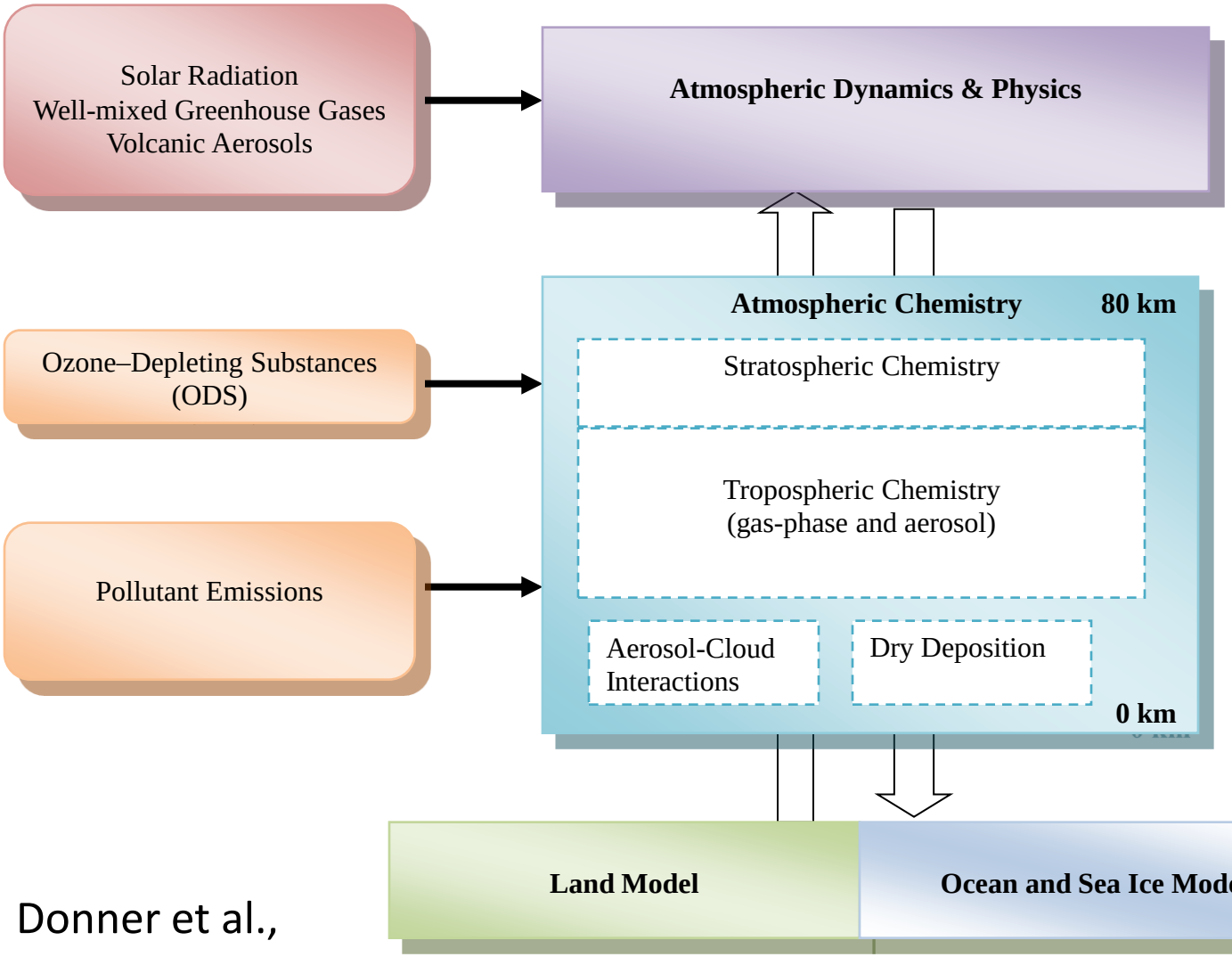
3. CM2.x

Decadal predictability research using GFDL's ensemble Kalman-filter analysis. Begin with CM2.1, advancing to higher resolution/complexity (CM2.5).

4. HiRAM

High resolution time slice integrations with AM2 (incl. alternative physics), at 50km (C180) and 25km (C360) resolutions, forced by SSTs and sea-ice.

(1) CM3 Coupled Climate Model



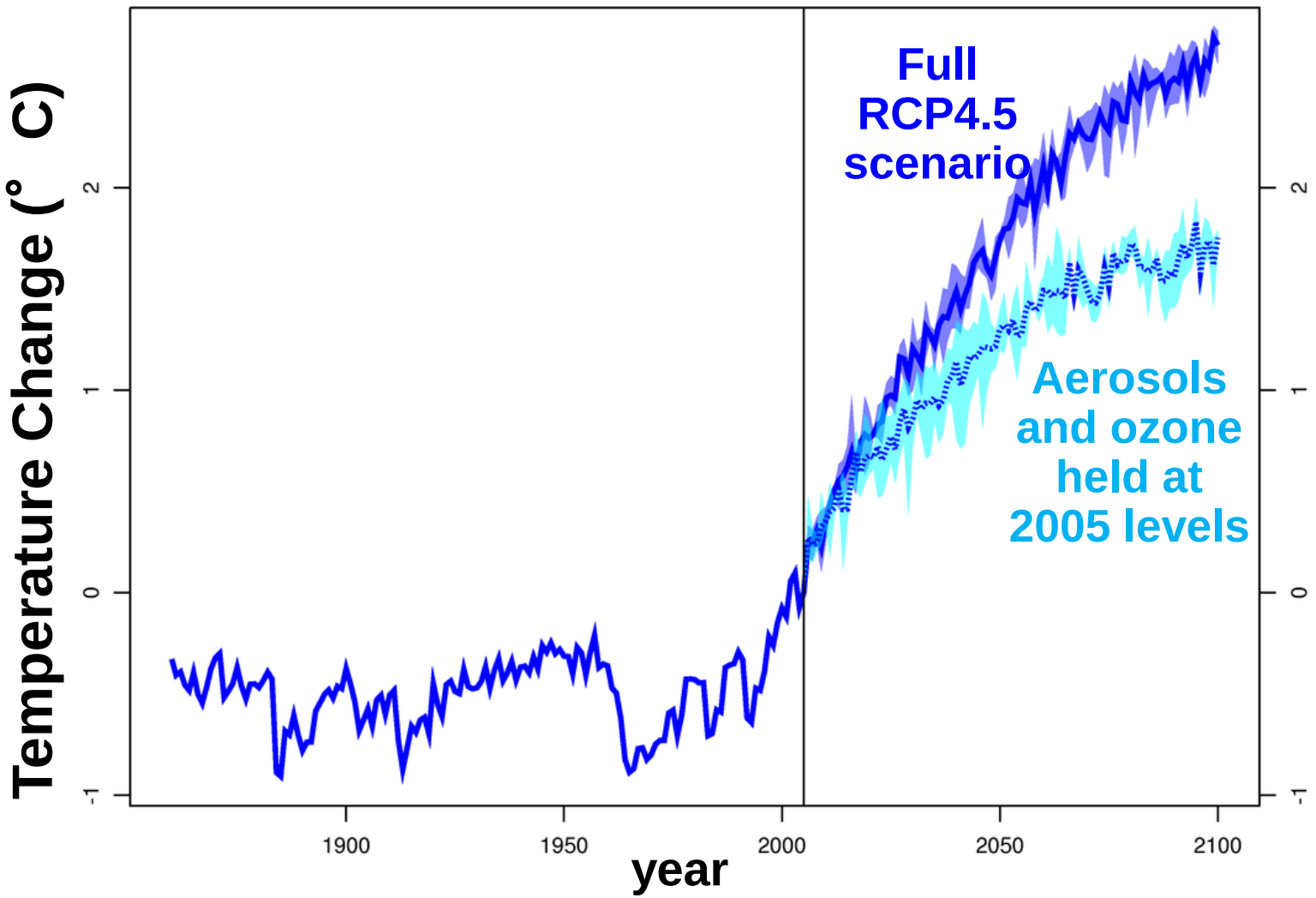
Designed to address:

- Aerosol-cloud interactions
- Chemistry-climate feedbacks
- Stratosphere-troposphere coupling

Donner et al., *J. Climate*, 2011

Slide courtesy of Larry Horowitz

Surface Air Temperature (RCP4.5 scenario)

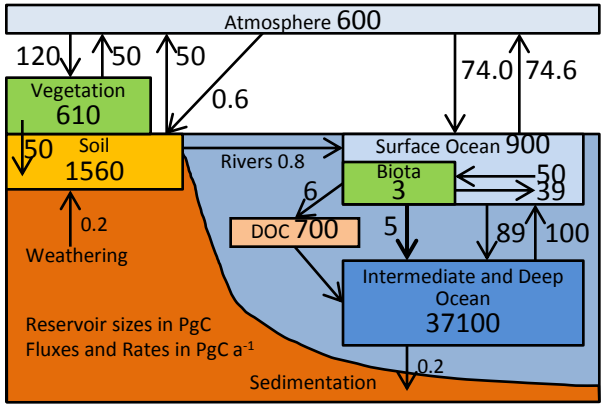


Large additional warming projected from aerosols over 21st century

Slide courtesy of Larry Horowitz

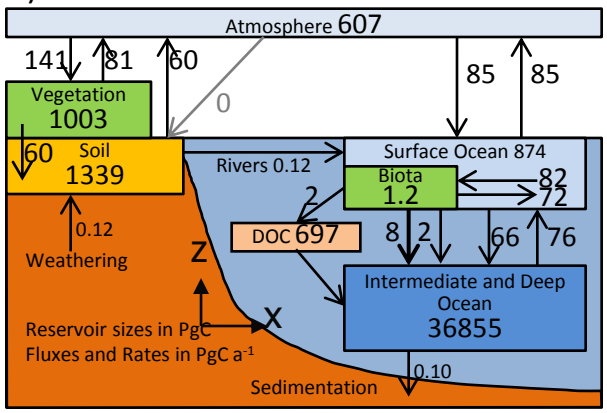
(2) GFDL's Earth System Models (ESMs) represent the major carbon cycle components and interactions with alternative ocean physical frameworks

A) Siegenthaler and Sarmiento (1993)*

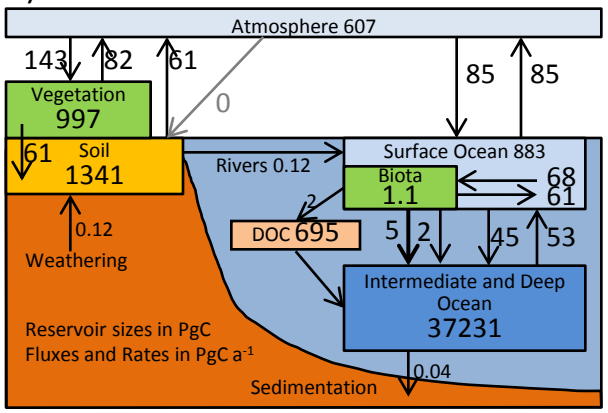


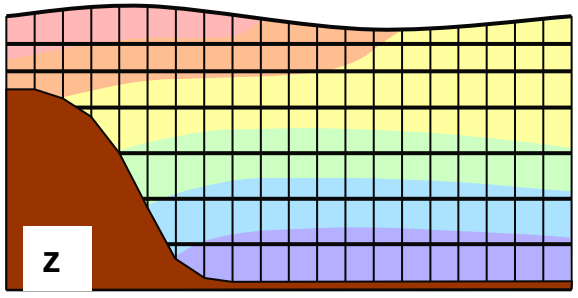
*includes modified ocean pools and fluxes (Sarmiento and Gruber, 2006; Sabine et al., 2004)

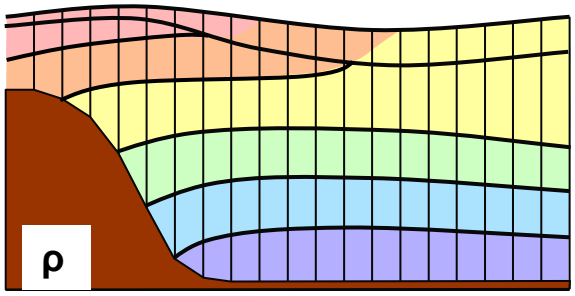
B) ESM2M



C) ESM2G







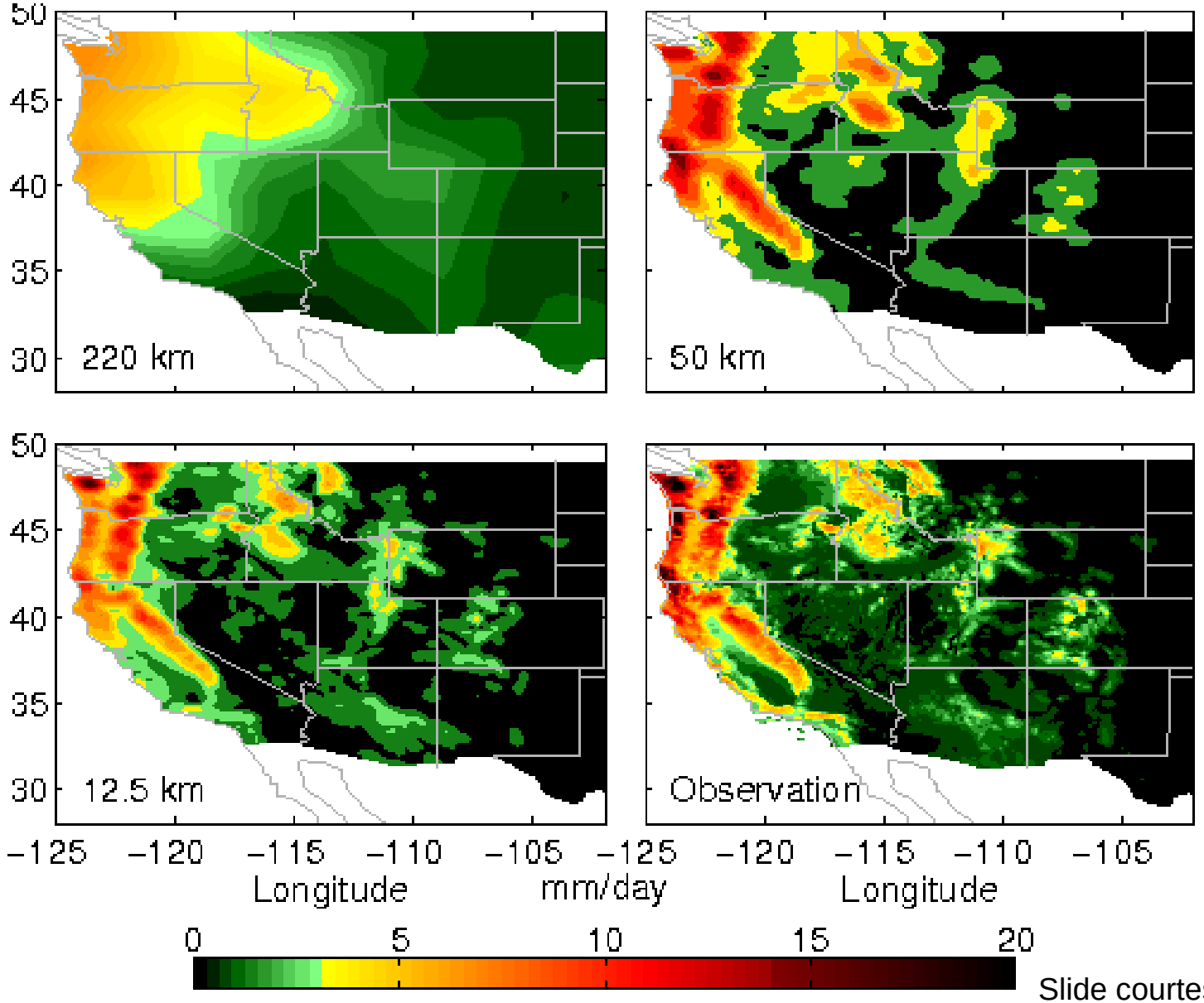
z* (MOM4.1):
- Laterally adjacent pressures interact
- Good representation of near surface
- Eulerian framework relatively straightforward to interpret
- Over 40 years of experience with it

ρ (GOLD):
- Laterally adjacent densities interact.
- Bulk mixed layer allows continuously varying mixed layer properties
- Good representation of overflows
- No numerical diapycnal mixing

Slide courtesy of John Dunne

(3) High-Resolution Models

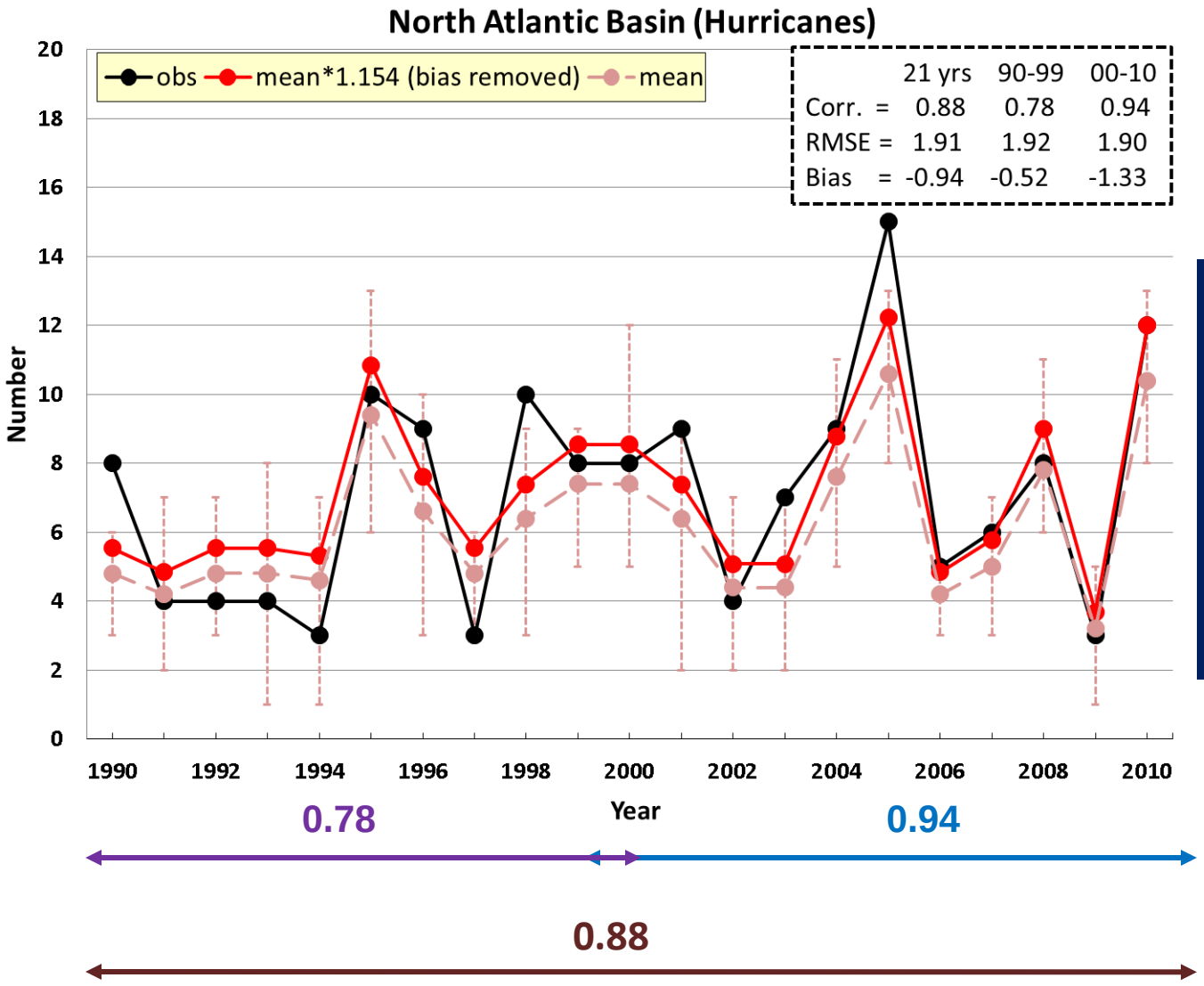
DJF Precipitation *GFDL models vs. PRISM*



Slide courtesy of SJ Lin

Seasonal hurricane predictions

1990-2010 (Jul-Nov)



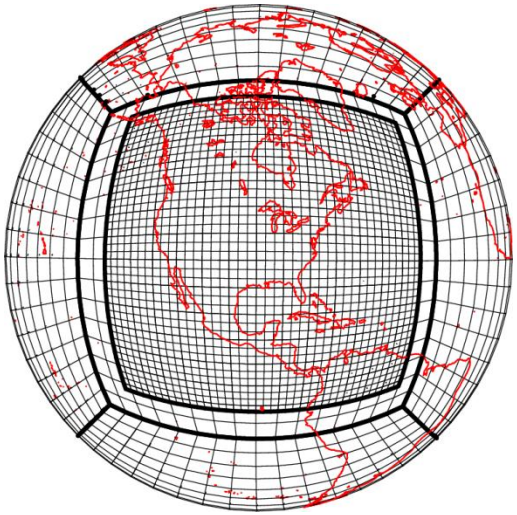
- Resolution: 25 km, 32 levels
- 5-members initialized on July 1 with NCEP analysis
- SST anomaly is held constant during the 5-month predictions
- Climatology O3 & greenhouse gases are used

1. Chen and Lin 2011, GRL
2. Chen *et al*., to be submitted

Slide courtesy of SJ Lin

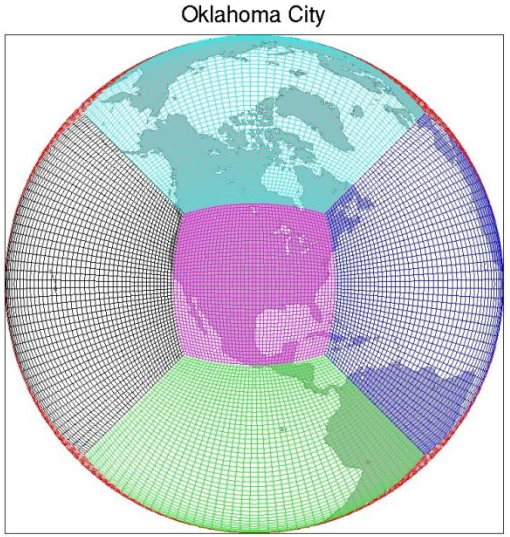
A. Nested regional-global climate model:

- 3X grid-size reduction; regional component can be run independently (for down-scaling) or coupled with global component to allow feedback to "global" changes



B. Variable resolution (via Schmidt transformation) climate model

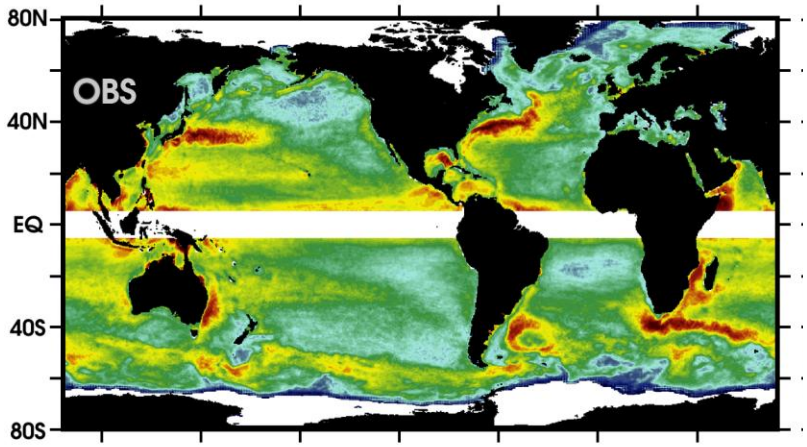
- Single model framework with smooth transition in resolution with 3X grid-size reduction in target region (e.g., NA with ~ 4 km resolution); 3X enlargement on the back side

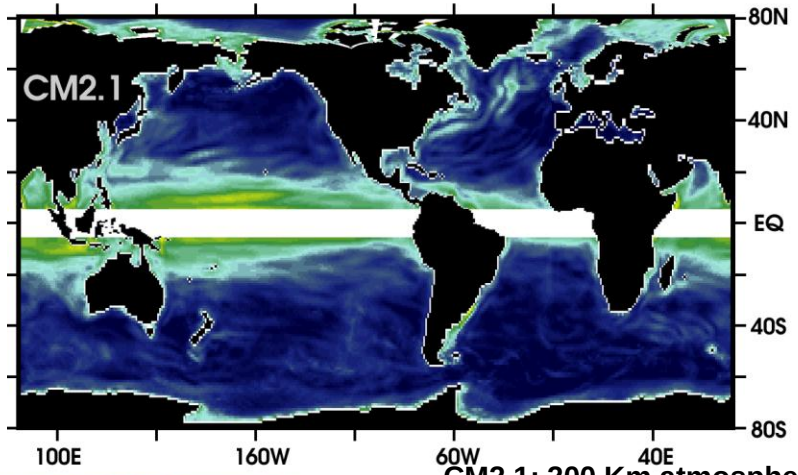


Slide courtesy of SJ Lin

Ocean mesoscale eddy kinetic energy (models and observational estimates)

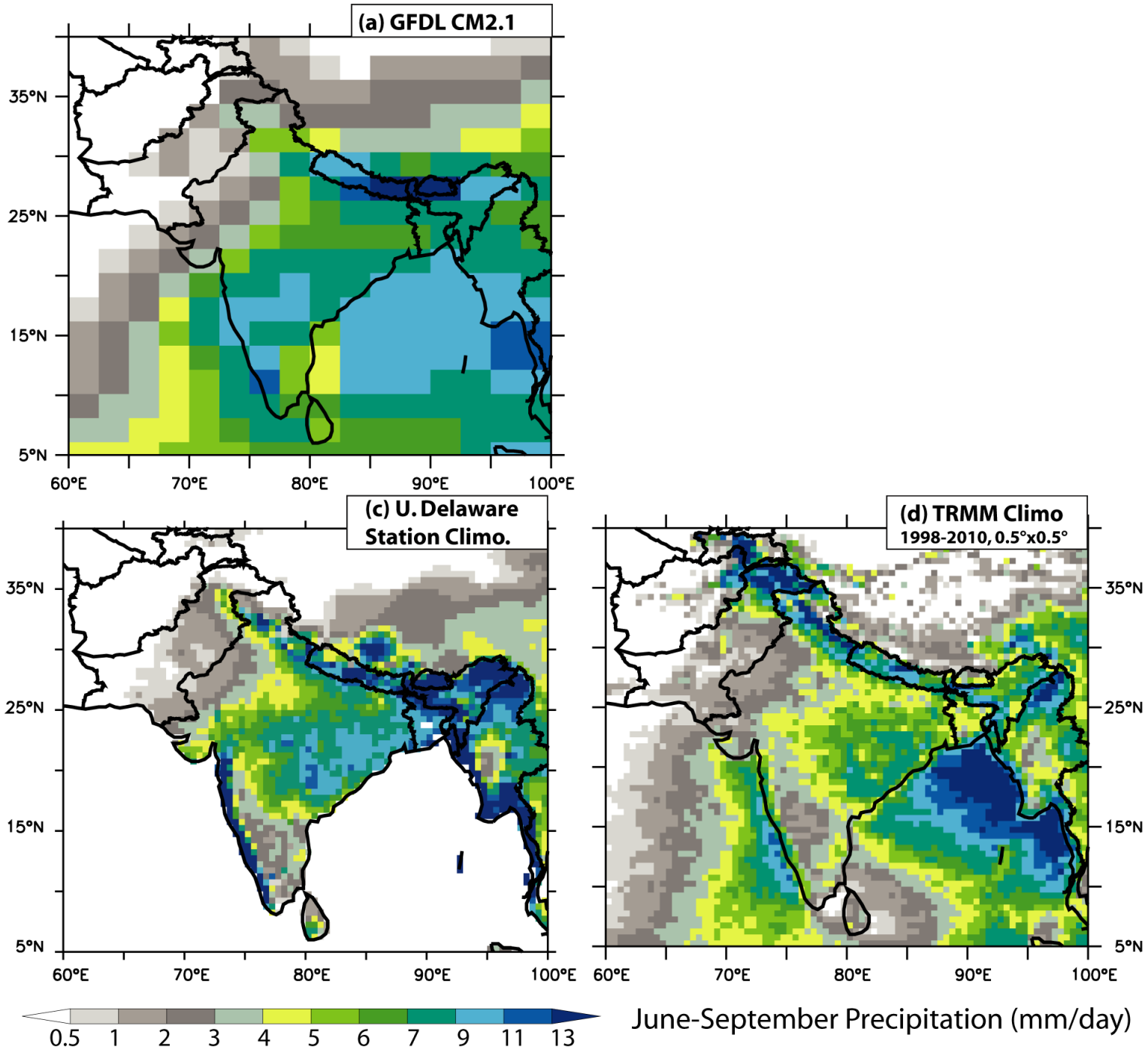
Observations
(derived from satellite altimetry)





CM2.1: 200 Km atmosphere, 100 Km ocean

Courtesy R. Zhang, K. Dixon


(a) GFDL CM2.1
(c) U. Delaware Station Climo.
(d) TRMM Climo
1998-2010, 0.5°x0.5°
35°N
25°N
15°N
5°N
60°E
70°E
80°E
90°E
100°E
0.5
1
2
3
4
5
6
7
9
11
13
June-September Precipitation (mm/day)

(4) Initialized Prediction Research at GFDL

SEASONAL:

- **Experimental predictions for tropical storm activity using both statistical and high-resolution dynamical models**
- **Use CM2.1 global coupled climate model and Ensemble Coupled DATA Assimilation System (ECDA) for experimental seasonal prediction; participate in US National Multi-Model Ensemble**

DECADAL:

Fundamental research questions:

- **What decadal predictability exists in the climate system?**
- **What are the mechanisms responsible for that predictability?**

Weather and climate variability and change:

Days to weeks: Midlatitude storms, baroclinic instability

Seasonal prediction: El Nino/Southern Oscillation (ENSO)

Decadal prediction(?): Atlantic Meridional Overturning Circulation

Decadal to centennial change: Radiative forcing changes

Initialized Prediction Research at GFDL

DECADAL:

- **Extensive research on:**
  - ✓ **Mechanisms of decadal variability and predictability (especially AMOC)**
  - ✓ **Roles of internal variability and radiative forcing changes**
  - ✓ **Requirements for observing systems for decadal predictions, including AMOC**
  - ✓ **Development of high-resolution and more realistic models to better simulate decadal variability and predictability**

- **Extensive set of decadal-scale hindcasts/predictions using CM2.1, with initial conditions each year from 1961 to 2012. Output publicly available as part of CMIP5 (over 5000 simulated years).**

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Circa 2015

CM4/ESM4 - drawing on what is learned from these various streams:

High resolution, biogeochemical cycles, ice sheet model, aerosols and chemistry, capable of initialized predictions across range of time scales